An Overview of Flight Computer Technologies for Future NASA Space Exploration Missions

Leon Alkalai
Center Director
Center for Integrated Space Microsystems
Jet Propulsion Laboratory
California Institute of Technology

1. INTRODUCTION

The development of advanced, high-performance flight computers designed and manufactured for long-term use in space, is of great interest to future NASA Space Science, Earth Science, Aeronautics, and Human Exploration and Development of Space applications. Moreover, highly integrated and embedded flight computers are an enabling technology for current and future commercial as well as strategic applications. In fact, flight computing technologies are a critical technology for the growing number of civilian applications that address commerce, communications, agriculture, energy, weather monitoring, science, education, etc.

That advanced computing technologies can revolutionize space applications should come as no surprise. Over the past several decades, computers have become increasingly ubiquitous on Earth, and have thus impacted every aspect of our lives. Some scientists compare the Information Technology revolution ushered by advances in computer technologies, with the agricultural and industrial revolutions of the past.

There are several important impediments that delay the transition of the commercial technological revolution into space. Most notably are the extreme environmental conditions characteristic of space including: numerous radiation effects, extreme temperature conditions, vacuum, and the combination of all the above. Furthermore, the remote and inaccessible and critical nature of the applications require special design, engineering, and manufacturing to enable high reliability, remote and on-line testability, self-diagnostics, fault-tolerance, and in most cases high-availability. Finally, given the inherent high cost of such reliable space computing systems, and the inherently small market for such applications, space systems must settle for both older technologies as well as the less frequent insertion of new generations of technologies into space.

In this paper, we present an overview of current developments by several US Government agencies and associated programs, towards high-performance single board computers for use in space. Three separate projects will be described; two that are based on the Power PC processor, and one based on the Pentium processor. All three projects

use a local electrical bus interface based on the commercial standard Peripheral Component Interface (PCI), as well as the design of single board computers based on the 3U Compact PCI (cPCI) mechanical interface.

2. A Brief History of Space Flight Computers

Throughout the space exploration era, NASA has relied on the commercial sector to provide flight computers and associated high-reliability computer technologies. However, early research and development efforts such as the Jet Propulsion Laboratory Self Test And Repair Computer (STAR), as well as research at other national laboratories has guided the industry with target space requirements, space qualification testing, etc. Even so, it was not unusual for NASA engineers to develop unique components, modules, and electrical interfaces that were applicable only to one (or very few) space applications.

As it became evident in the early 80s that the commercial computer revolution was growing at an exponential rate, NASA made more explicit decisions to increasingly leverage developments in the commercial sector. Most notably, the Cassini project which launched in October 1989 and is now on route to Saturn, co-developed the first computer based on the Generic Very High Speed Integrated Circuit (GVHSIC) technology, as a contract to IBM Federal Systems. This four-chip computer chip-set was used as part of the Common Flight Computer (CFC), called so, because there was one flight computer common to all of the spacecraft subsystems.

The following generation of flight computer technologies was introduced by the Mars Pathfinder project, launched in December 1996. This project further pursued the approach of infusing computer technologies from the commercial sector. The MPF Computer was based on the IBM R6000 architecture and developed by Lockheed Martin Federal Systems (previously IBM Federal Systems). A single-board computer was developed based on the VME commercial electrical and mechanical interface standard. Moreover, the computer was, for the first time, using the commercial VxWorks real-time operating system and the C programming language.

As discussed in the following section, NASA is currently developing another generation of computer technologies that will most likely set the tone for the first decade of the new millennium of space exploration.

3. Next Generation Space Flight Computers

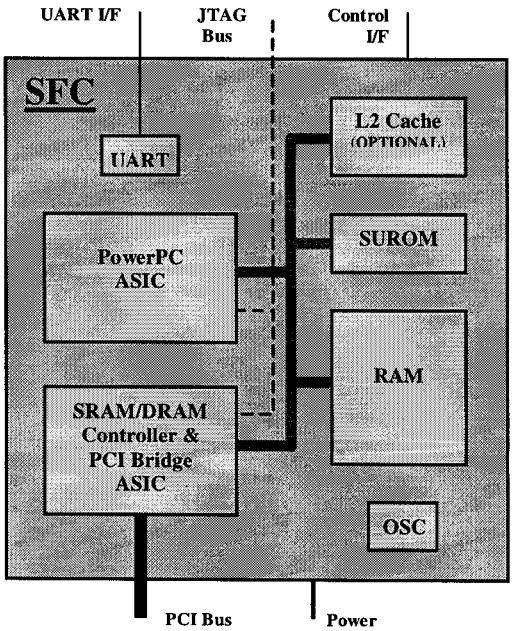
NASA's Outer Planets Program is currently in the final stages of completing the development of the X2000 System Flight Computer (SFC). This computer was originally designed as part of the X2000 Technology Program for the Europa Orbiter Project which was scheduled for launch in November 2003. Whereas this project is now scheduled for launch in March of 2008, the technology is still being completed on its original schedule, and will thus be inserted into other earlier NASA missions. This computer is based on the Power PC 750 processor, and is being developed by British Aerospace Federal Systems. The electrical and mechanical interfaces are based on industry standards, including the

local bus architecture of the Peripheral Component Interface (PIC), and the Compact PCI (cPCI) chasis.

Parallel to this development by NASA's Europa Project, there are two more developments in place. The US Air Force is funding the Power PC 603e processor under development by Honeywell, and the Department of Energy in collaboration with other government agencies (including NASA) is developing a processor chip-set based on the Pentium I processor. All three processors are characterized by high-performance relative to previous generations, with target specifications reaching (or exceeding) 200 MIPS rate (millions of instructions per second). Moreover, these processors are being designed with space applications in mind, that is, they have circuit design enhancements to reduce the rate of single-event upsets due to radiation. The processors also have extensive support for low-power modes, floating point execution, on-chip caching (Level 1 cache), off-chip cache support (Level 2 caches), virtual memory support, and other features normally found in commercial processors. The following sections briefly summarize each project and their status.

3. 1. Power PC 750 System Flight Computer (SFC)

The Europa Project is currently developing the System Flight Computer (SFC) as a standard single board computer for space applications. As shown in Figure 1 below, the computer board is based on the 3U cPCI mechanical specifications, and the PCI electrical interface. The main compute engine comprises of the PPC 750 chip running at 133 MHz. The PCI bus interface and other associated functions are implemented in the PPC Bridge chip running at 66 MHz. Also on the computer board are 128 Mbytes of Dynamic Storage (DRAM), a clock, and small non-volatile storage for board configuration (SUROM), and support for on-line testing using the JTAG bus. The board is operating at a 3.3 volts with the CPU core internally operating at 2.5 volts. The flight computer is specified for a mission life cycle of 14 years in the worst case environment.



3.2 Rad Hard Pentium (RHP) Project and PPC 603e

In addition to the PPC 750 development by the Europa Project, the US Government is also developing two other designs, based on the PPC 603e (Honeywell) and the Pentium I processors (Sandia National Laboratories). In both cases, the development of the chip set includes two chips: the Central Processing Unit (CPU) and the 'bridge' chip, which provides the interface to memory and the local bus. In all cases, the local bus adopted is the PCI bus, whereas the mechanical interfaces include (but are not limited to) the compact PCI (cPCI) design.

The major difference between the two processors is that the Pentium I design and implementation will favor survivability in high-radiation environments, whereas the PPC 603e will favor more low-power applications. A more detailed comparison of the three high-performance single-board computers is under study.

4. Conclusions

Next generation spacecraft will be controlled by high-performance flight computers that are designed for long-term exposure to the harsh environments found in space. The flight computer under development by the Europa Orbiter project is designed to survive the extreme environmental and especially radiation conditions around Jupiter and Europa. The System Flight Computer (SFC) is based on the commercial PPC 750 processor with a target performance of 200 MIPS. In parallel, there are two other high-performance processors being developed in the US. The Power PC 603e and the Pentium I are both under development by industry, and sponsored by other government agencies. All three processors and their associated interface chips are designed to support the same electrical, logical, and mechanical interfaces. This will allow for the inter-operability of flight computers that have different CPU chips sets, just as is the case in the commercial world. A more detailed comparison of the three processors shows that they actually may be applicable to different mission needs, ranging from high-radiation environments, to low-power applications in space.

References:

"X2000 System Flight Computer, SFC Enhancement Performance Specification," JPL-D-19951, December 20, 2000.

"Rad Hard Pentium Project, RHP," Sandia National Laboratories.